Nonlinear and Dissipation Characteristics of Ocean Surface Waves in Estuarine Environments

James M. Kaihatu
Zachry Department of Civil Engineering, Texas A&M University
3136 TAMU
College Station, TX 77843-3136
phone: (979) 862-3511 fax: (979) 862-8162 email: jkaihatu@tamu.edu

Alexandru Sheremet
Engineering School of Sustainable Infrastructure and Environment, University of Florida
P.O. Box 116580
Gainesville, FL 32611

Jane M. Smith
Coastal and Hydraulics Laboratory, U.S. Army Engineer Research and Development Center
3909 Halls Ferry Rd.
Vicksburg, MS 39180
phone: (601) 634-2079 fax: (601) 634-4314 email: Jane.M.Smith@usace.army.mil

Hendrik L. Tolman
National Center for Environmental Prediction, National Oceanic and Atmospheric Administration
5200 Auth Rd. Rm 209
Camp Springs, MD 20746
phone: (301) 763-8133 x7253 fax: (301) 763-8545 email: Hendrik.Tolman@noaa.gov

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LONG-TERM GOALS

The overall goal of this work is the development of computational modules for the dissipation of surface wave energy due to expanses of bottom mud and marshland vegetation. The computational modules would represent both the dissipative effects on the surface waves and the effects of dissipation on other processes of wave transformation and evolution. In addition these modules would allow for feedback between the surface wave and the energy dissipating feature.

OBJECTIVES

1) Develop processes models of the physics of dissipation in estuarine areas.
2) Use optimized ensemble simulations to represent effects of dissipation on wave processes.
3) Develop and test low-dimension, reduced representations of estuarine effects for inclusion into operational wave models.

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4) Develop experimental versions of operational wave models.

APPROACH

We will first work to develop computational models for detailed, phase-resolved predictions of wave dissipation in estuarine areas. These models will include various mud proxy models (viscous fluid, viscoelastic semi-rigid bed, Bingham plastic) for wave/mud interaction and mud-induced dissipation. These proxy models for mud dissipation have fairly broad-banded responses over a large swath of wave frequencies, so they can be expected to inhibit various nonlinear interactions in the random wave field. The task here will be to surmise whether this frequency dependence is scalable or self-similar over a range of frequencies, conditions or proxies. In addition the feedback between surface and lutocline waves will be investigated to determine whether or not these interactions have an effect on surface wave energy; allowing for surface-lutocline interaction can potentially *redirect* surface wave energy rather than simply dissipate it. A similar line of inquiry will be performed for wave-vegetation interaction, though the expected parameter space for this phenomena may be significantly reduced compared to mud dissipation. These models will be validated with available data.

To make this suitable for a random wave spectral model (as most operational wave models are), we must find ways of randomizing our results with the deterministic models. One possible method would be the use of a neural network approach, which uses data from the models to establish a "training set" which helps predicts future behavior. The neural network mapping strategy of Krasnopolsky et al. (2002) will be one candidate for use; it was used for the Wavewatch-III © model, and should be available for use here.

In addition, and in concert with the project "Development of Numerical 3-Wave Interactions Module for Operational Wave Forecasts in Intermediate-Depth and Shallow Water" (PI: Sheremet; co-PI: Kaihatu) we will investigate physically-justifiable reduced dimension models which will retain the dominant components of wave-mud-vegetation interaction but will also allow for more expedient calculation. Furthermore, for further application of the model to a wider range of areas, we are also investigating the dissipation of waves over steep bathymetry, such as reefs.

Finally we will make use of the models developed above to create experimental versions of operational models. This will allow us to test the physics in the developed models while using the general framework of operational wave models. We will conduct robustness tests of the system to determine the conditions under which the new models exhibit sub-optimal behavior. We will also work with the NCEP and NAVO (if available) operational forecasters, as well as the scientific community at the Naval Research Laboratory (NRL) and Engineering Research and Development Center (ERDC) to insure smooth incorporation of these developments into their operational run stream.

The TAMU team consists of the PI (Kaihatu); an M.S. students (Mr. Aravinda Venkattaramanan); and two Ph.D. students (Ms. Samira Ardani and Mr. John Goertz). Ms. Ardani is working on quantifying the performance of nearshore nonlinear models with field data and reforumlating them for more comprehensive performance. Mr. Goertz is quantifying the dissipation which occurs over steep bathymetry. Mr. Venkattaramanan is investigating nonlinear wave processes through vegetation. The UF team consists of Alex Sheremet (PI), Miao Tian and Cihan Sahin (Ph.D. students) who are working on modeling nonlinear wave evolution in dissipative environments (mud), and the response of sea bed

to wave action. In addition, a research assistant scientist (Justin Davis) has been working on testing a directional nonlinear wave code and implementing this into the WAVEWATCH-III model.

WORK COMPLETED

The nonlinear wave-vegetation dissipation model (essentially the model of Kaihatu and Kirby 1995 with the vegetation dissipation model of Kobayashi et al. 1993 incorporated) was validated with laboratory data from the US Army Corps of Engineers (Anderson and Smith 2013). Since time series from the experiments were available, both wave spectra and higher-moment statistics (skewness, bicoherence) were compared between data and model.

The dispersive nonlinear model of Kaihatu and Kirby (1995) was compared to data from the Duck94 experiment. A weakly dispersive, weakly nonlinear wave model (Freilich and Guza 1984) was also compared. While comparisons to wave spectra appeared to match expectations, the weakly dispersive model appears to capture wave shape statistics better than the dispersive model. It is hypothesized that the dispersive model does not transition free random waves to a “locked” state at the proper rate in the shoaling process, and that the lack of an explicit non-resonant bound wave relationship in the model may be a contributing factor to this lack of accuracy. It is also hypothesized that the weakly dispersive model, with its assumption of near-resonance, may “mimic” the missing bound wave process, at least through much of the shoaling process. We have developed a third order extension of the model of Kaihatu and Kirby (1995) and are now testing the model against various data sets.

A directional spectral model (Agnon and Sheremet 1997) was developed and tested. The model implementation includes: incorporation of offshore wave spectra; remapping of frequency-directional spectra into frequency-longshore wave number grids; and snapshots of the free surface elevation. At present the model is being tested with Duck AWAC (Acoustic Wave and Current) data. Coupling with the WAVEWATCH-III model is ongoing, and comparisons with nonlinear parabolic models and phase-averaged neaershore models are being planned.

RESULTS

Validation of Nonlinear Wave-Vegetation Model: Figure 1 shows the experimental setup of Anderson et al. (2013) and comparisons between wave spectra, root mean square waveheight, and skewness. While H_{rms} comparisons look quite favorable, some deviation between data and model are shown in the comparisons to spectra; the model appears to overpredict the energy in the frequency range above the spectral peak. While the overall energy level relative to the peak is small in this range, this has a cumulative effect on the prediction of wave shape; skewness is generally underpredicted by the model. It is likely that adjustments to the dissipation mechanism (perhaps switching from a deterministic model to one that is more probabilistic in nature) will help with the underprediction.

Directional Triad Interaction: Figure 2 shows a comparison between three free surface elevations fields, all of which are realizations from the nonlinear directional triad model; waves are moving from offshore (bottom) to onshore (top) in each plot. The top surface plot shows the result from a linear model, while the middle surface plot shows the result with the directional triad interactions activated. The nonlinear natiure of the waves in the nearshore is shown via the narrowing of the crests at the top of the middle plot. The botton surface plot is the nonlinear free surface elevation field after low-pass filtering (frequencies less than 0.05 Hz), and is representative of the infragravity wave field. Validation of the model’s performance is to be accomplished over the next year.

IMPACT/APPLICATIONS

The present research extends the predictive capability of the Navy's wave forecasts by treating areas that are far removed from the non-cohesive sedimentary environments which have underpinned work in wave propagation. These mechanisms, when incorporated into operational Navy wave prediction models, can improve operational predictions in shallow, muddy areas or areas with steep bathymetry.

RELATED PROJECTS

None.

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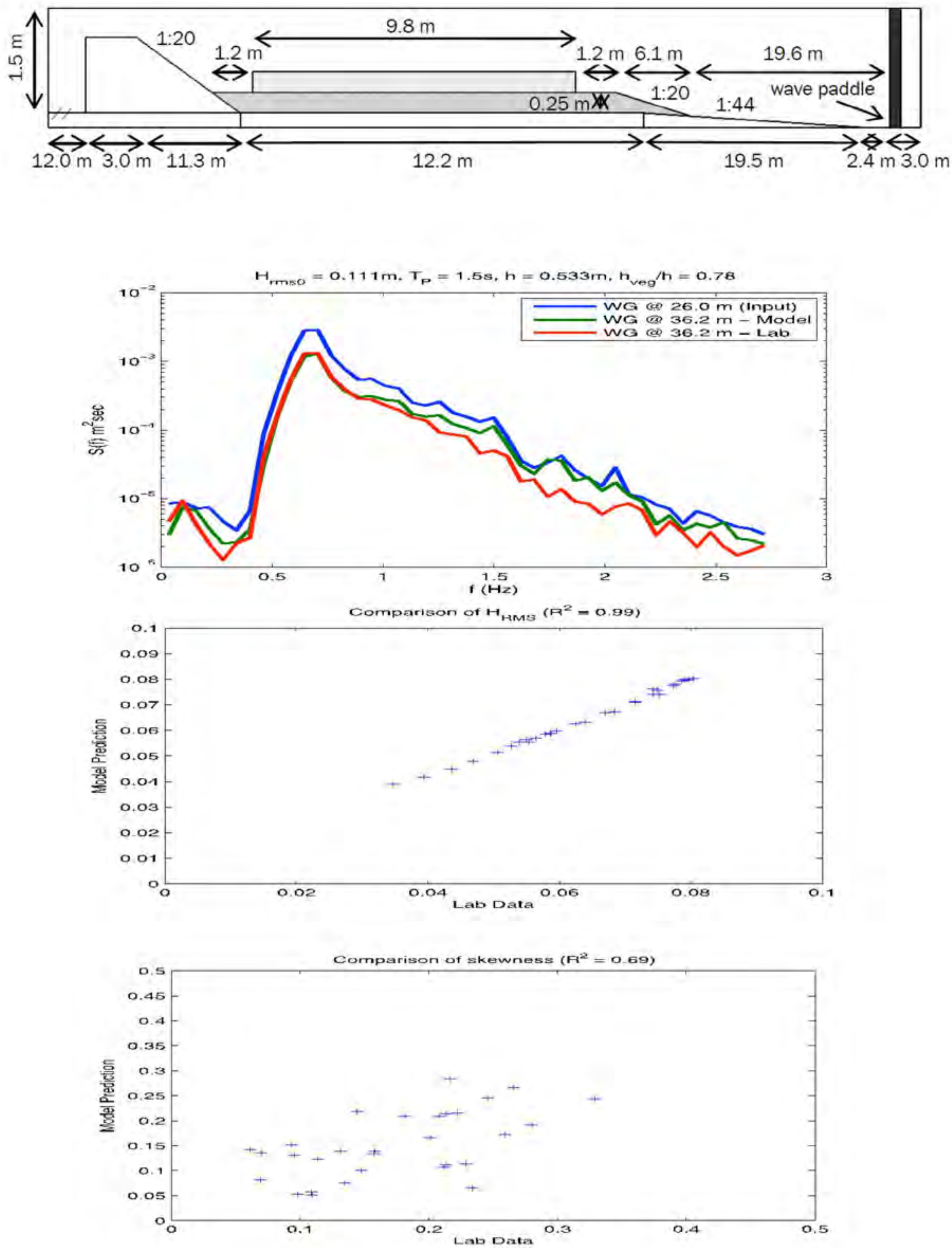

Figure 1: Nonlinear wave-vegetation model comparisons with data from Anderson et al. (2013). From top: Experimental layout; comparison of wave spectra at downwave end of vegetation (green is model, while red is measurement); root-mean-square waveheight comparison between prediction and measurement; and skewness comparison between prediction and measurement.

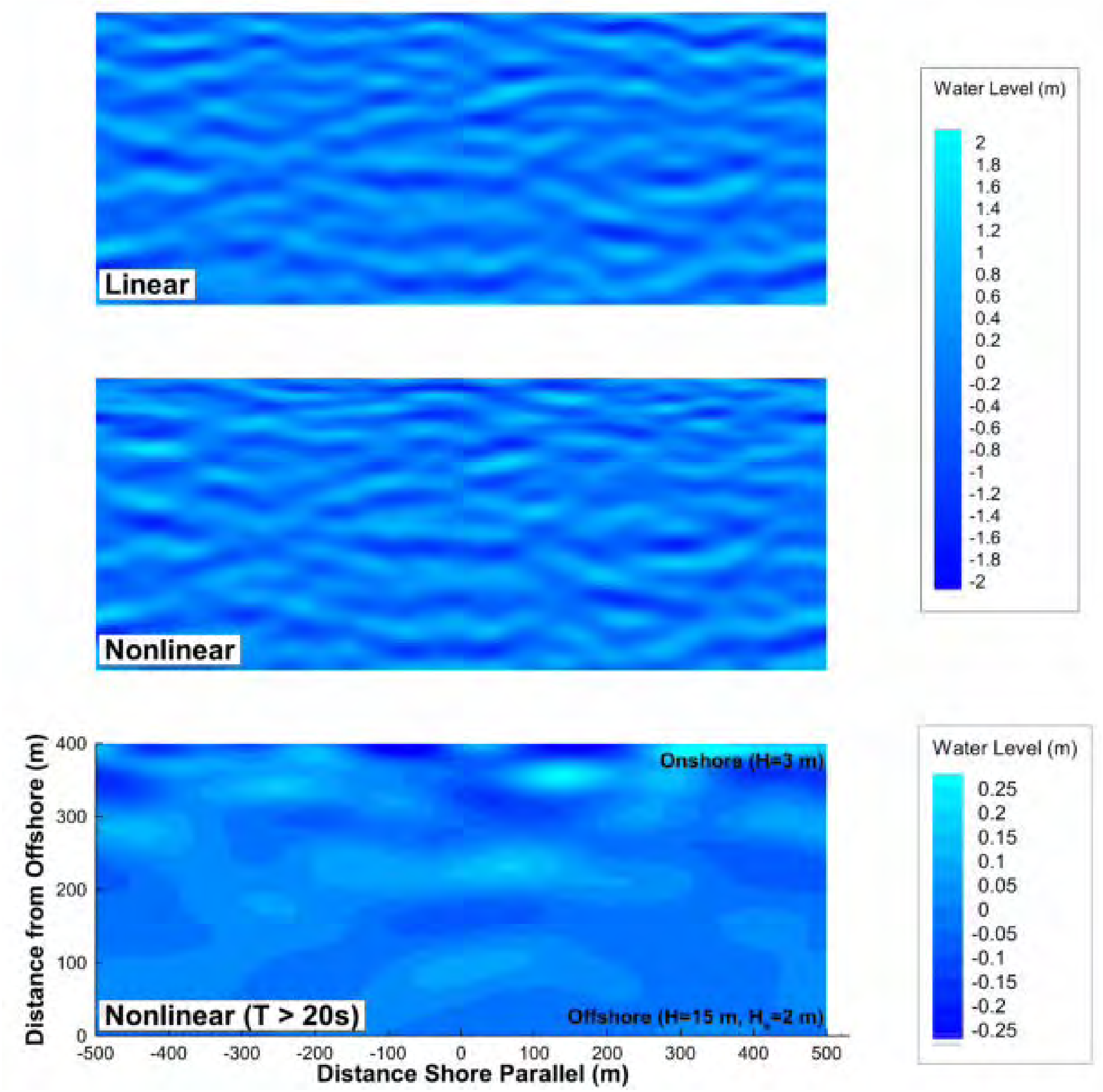

Figure 2: Free surface elevation realizations from the nonlinear triad directional model of Agnon and Sheremet (1997). Top: Linear model result. Middle: Nonlinear model result. Bottom: Low-passed filtered free surface elevation result from nonlinear model.